NASA Marshall Space Flight Center
Robotics Academy 2011

Automated Simulator for Docking Operations

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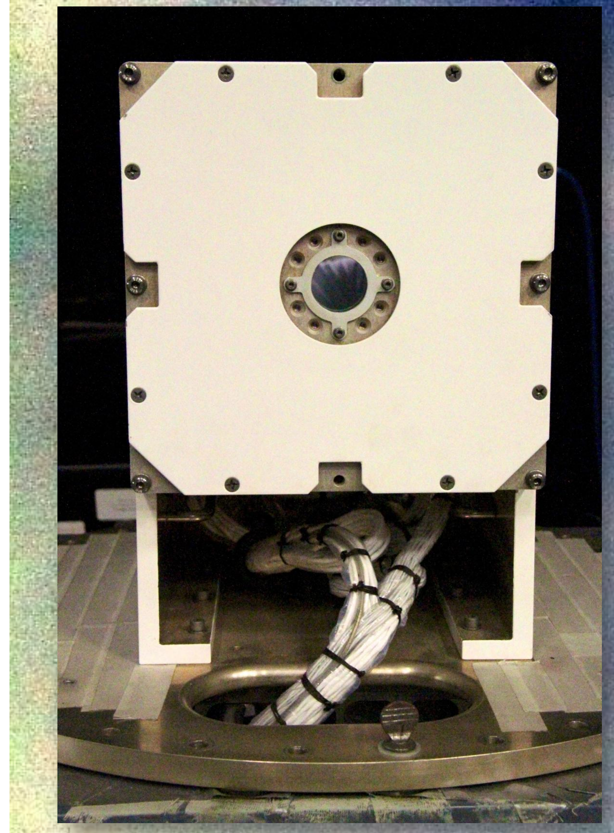
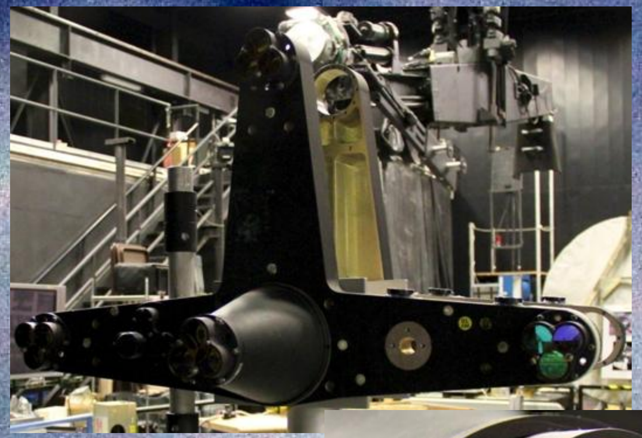
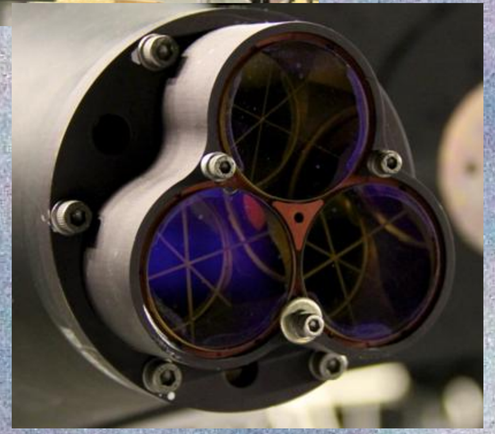






Abstract

The Flight Robotics Laboratory (FRL) at NASA's MSFC operates many robotic systems to assist in the development and testing of new technologies for avionics and dynamic control of spacecraft. Some of these systems include air-bearing vehicles, a 6-degree of freedom robotic arm, a dynamic solar simulator, and a tilt table. The Small Mobility Base (SMB) is one of the air-bearing vehicles in the FRL, and it is the one upon which we are working. The SMB was designed to investigate video-guidance systems, algorithms for calculating a space vehicle's relative position, automated docking operations, and control algorithms. Our project consists of re-programming and performance improvement for autonomous and manual operations. Some improvements we have accomplished include upgrading the control system to utilize more robust and efficient algorithms, increasing the efficiency of multi-sensor data acquisition, modular programming adaptation, enhancing system data logging capabilities, and implementing tele-operation and tele-presence capabilities. In addition, due to our re-organization and documentation, future upgrades will be easier and more cost effective.

Background

- The SMB was developed by several NASA employees until the last modification in 2008.
- They documented important information about their project , but it was insufficient, leaving us to figure out how some processes worked ourselves.
- Summer 2011: We started up the SMB in hope of reviving it, but countless issues arose with the existing LabVIEW programs and operating system.
- We deduced a new plan; rewrite the LabVIEW programs using the existing programs as a base to work from.
- The new LabVIEW programs include:
  - Algorithms for improved thruster selection and autonomous piloting
  - Upgraded control systems (manual & autonomous control)
  - Tele-operation & tele-presence capabilities
  - Efficient multi-sensor data acquisition
  - Improved system data logging capabilities
  - Organized documentation & programs for easier upgrades

Method and Materials

- Sensors to read relative position: Video Guidance Sensor, Laser Range Finders
- Sensors for dynamic motion feedback: Gyroscope, Load Cells and Accelerometers
- Controls for motion: Solenoid valves with machined orifices to fire 1 lb and 3 lbs cold gas thrusters, air-bearings and high pressure air tanks
- Powering devices: 24V re-chargeable batteries, AC inverter
- Data Acquisition devices: National Instruments USB DAQ device, DELL laptop
- Communication devices: Serial to USB communication adapters
- Operating system & programming software: Windows XP, NI LabVIEW 2010
- Programming methodology: Block programs to separate basic individual tasks and a main program to integrate and manage all sensors, controls and algorithms

$$P_{k+1} = P_k - \frac{RT(\propto F_{1lb} + \beta F_{3lb})}{g_c I_{SP,k}(V_{plenum} M_{W,air} + 2\gamma_{inlets} R T_c \rho A_{cross}^2)} \Delta t$$

Theoretical pressure of SMB manifold/plenum after firing **α** 1 lbs thrusters and **β** 3 lbs thrusters for a **Δt** time step

$$I_{SP,k} = \frac{1}{g_c}\left\{\sqrt{\frac{2kR_sT_c}{k-1}\left[1-\left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right]} + \frac{P_eA_e}{P_cA_t}\sqrt{\frac{R_sT_c}{kg_c\left(\frac{2}{k}+1\right)^{\frac{k+1}{k-1}}}}\right\}$$

Thermodynamic equation for theoretical specific impulse ($I_{SP,k}$)

Brown, C. D. (2002). *Elements of Spacecraft Design.* Castle Rock, Colorado: American Institute of Aeronautics and Astronautics (AIAA).

$$P_\alpha(\Delta\alpha) = (T_\alpha - O_\alpha) * \frac{1}{1+e^{-\frac{3\Delta\alpha}{2}+6}} + O_\alpha$$

Navigation (Logistic Function) – Generates waypoints between SMB and target following a modified logistical path

$$f = (F_r - F_p) + (\theta_r - \theta_p) + (\tau_r - \tau_p)$$

Fitness Calculation – Determines the fitness of a given solution in the solution space given a requested output

Kalman Filter – filters and smoothes the inputs of the accelerometers, while concurrently predicting the next state in terms of acceleration, velocity, and position

Time Update ("Predict")

(1) Project the state ahead

$$\hat{x}_k^- = A\hat{x}_{k-1} + Bu_{k-1}$$

(2) Project the error covariance ahead

$$P_k^- = AP_{k-1}A^T + Q$$

Measurement Update ("Correct")

(1) Compute the Kalman gain

$$K_k = P_k^- H^T(HP_k^- H^T + R)^{-1}$$

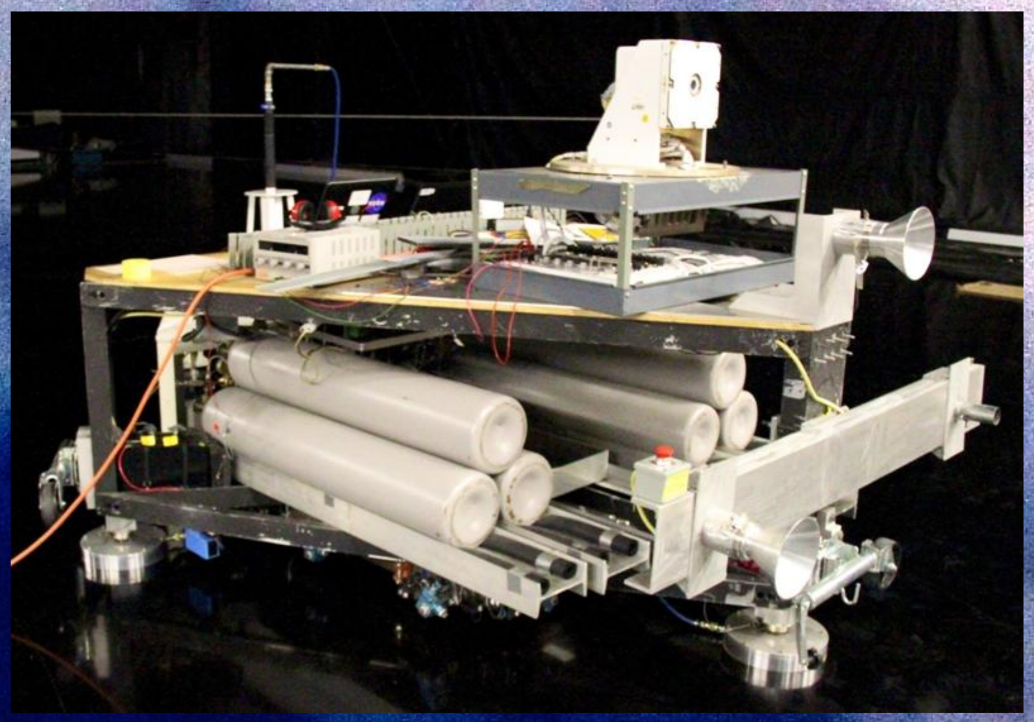
(2) Update estimate with measurement

$$\hat{x}_k = \hat{x}_k^- + K_k(z_k - H\hat{x}_k^-)$$

(3) Update the error covariance

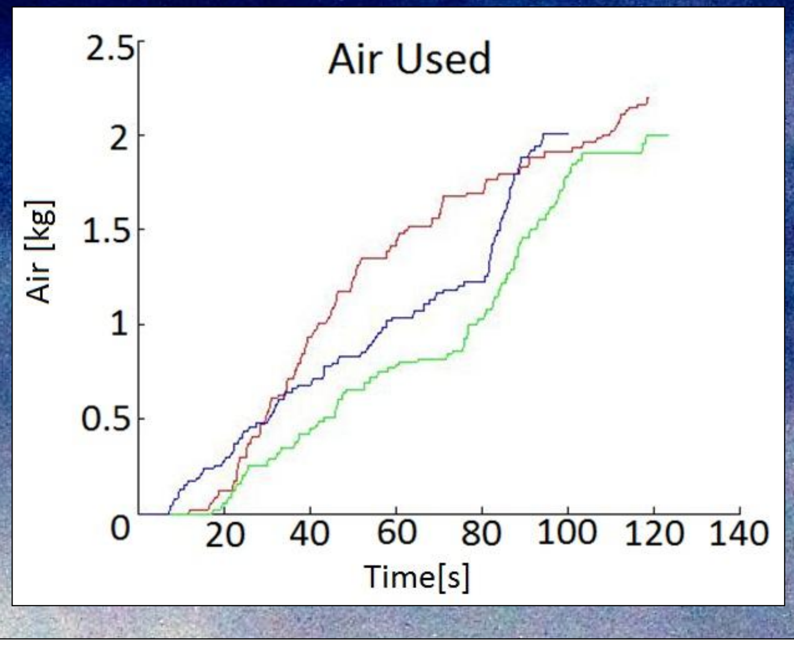
$$P_k = (I - K_kH)P_k^-$$

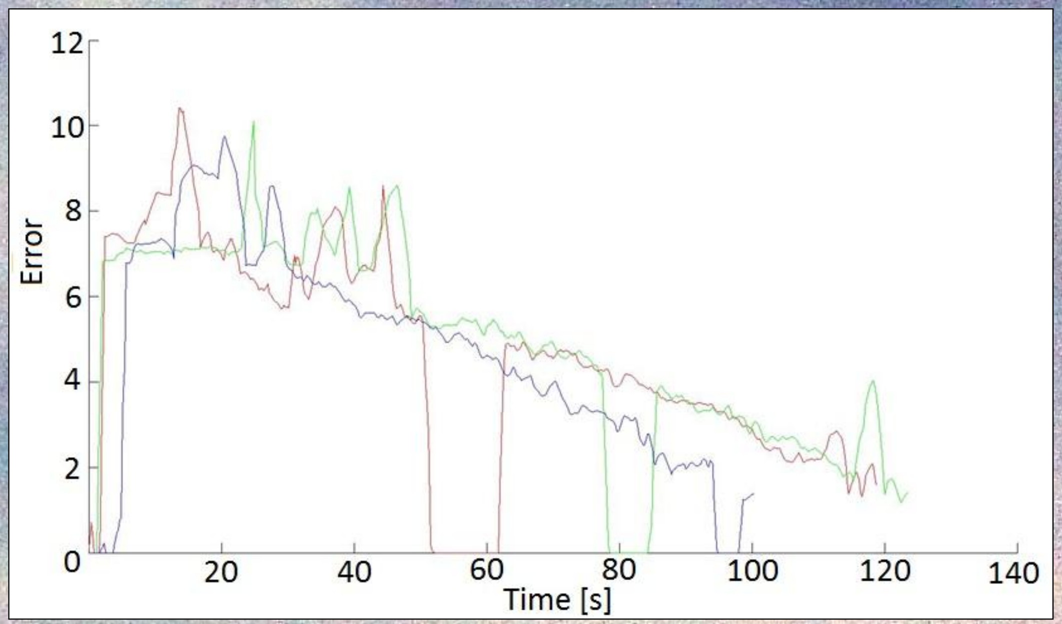
Initial estimates for $\hat{x}_{k-1}$ and P_{k-1}



Results

We collected data for manual control of the SMB and worked on autonomous control. Below are two graphs with results from three manual test runs showing the air consumed and the pilot's accuracy of staying on track.





Conclusion

- Organized programming allows for system integration, program debugging, and future modifications to easily be done.
- Block programming allows for high-capability hardware and its corresponding software to be more efficient and robust.
- The SMB provides the capabilities for testing sensors, algorithms, and hardware required for researching docking operations and maneuvering in space.
- Future improvements that could increase such capabilities include:
  - Creating an algorithm for docking to a moving target
  - Redesigning thruster nozzles to maximize air flow efficiency
  - Redesigning the geometry of the air-bearings to avoid bumps on the floor